

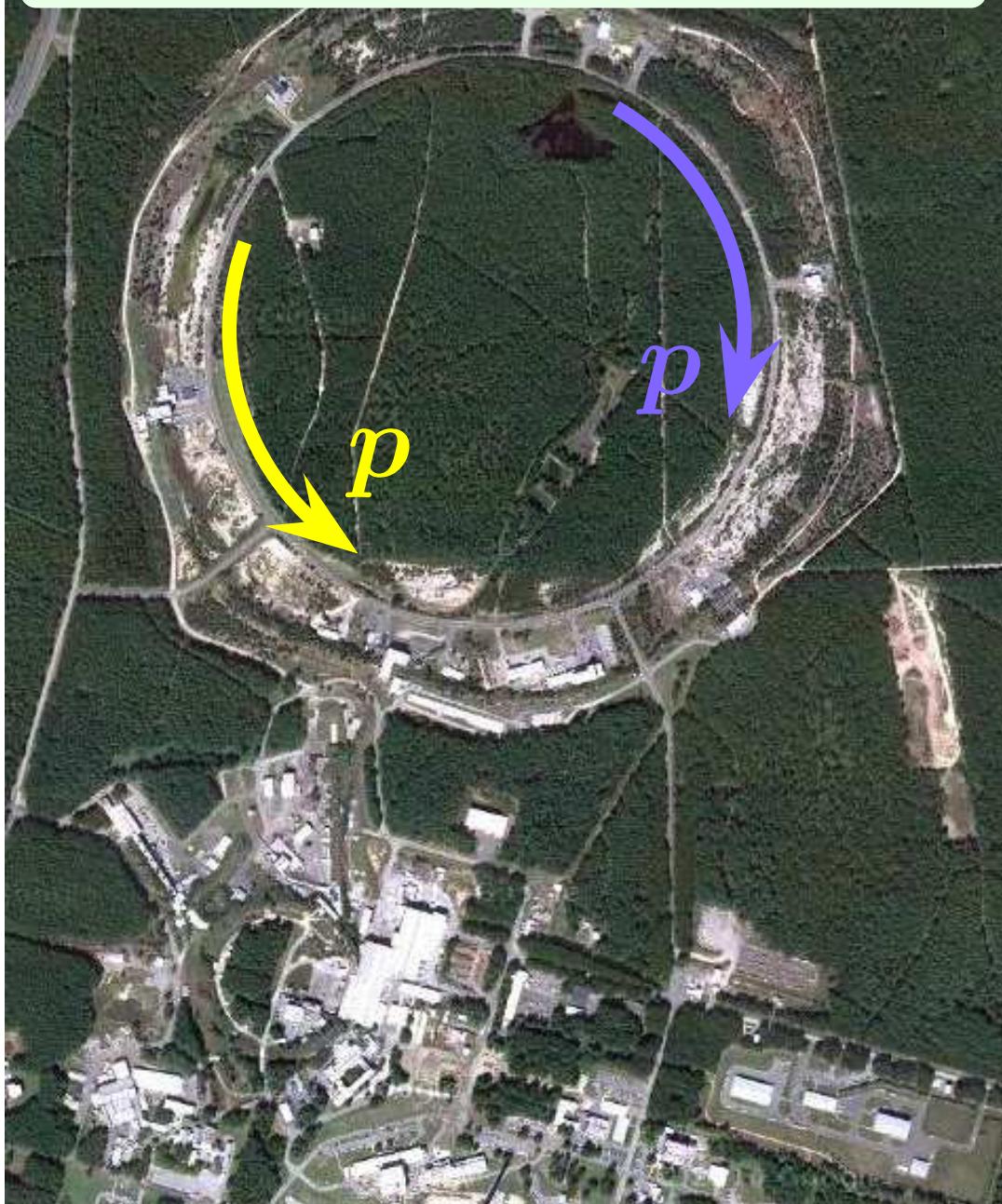
Measuring Proton Beam Polarization at Relativistic Heavy Ion Collider (RHIC)

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November 30, 2012

What Is RHIC?

Relativistic Heavy Ion Collider

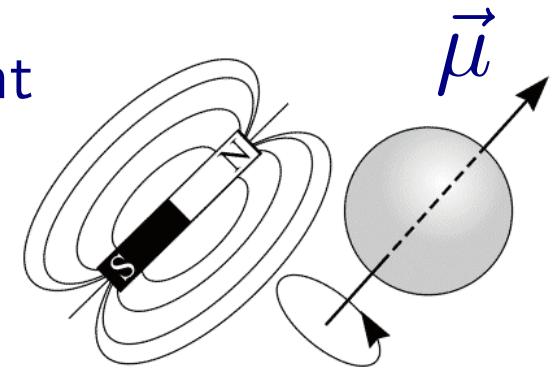


- **RHIC is the largest scientific tool at BNL**
 - Ring diameter is ≈ 0.75 miles
 - Accelerates subatomic particles **protons, deuterons, Si, Cu, Au, U** to nearly the speed of light
 - Collides particles head-on at two interaction points
- **RHIC is the first and only world's polarized collider**
 - In operation since 2000
 - Improving performance from year to year

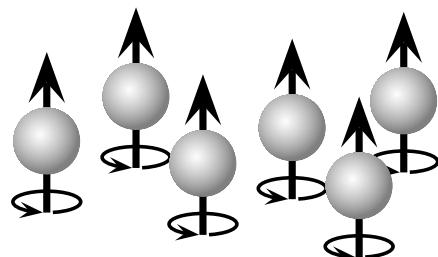
Polarized Protons

- Electrically charged particles possess a magnetic moment

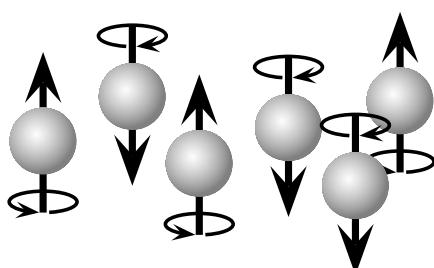
$$\vec{\mu} \propto \frac{q}{m} \vec{s}$$



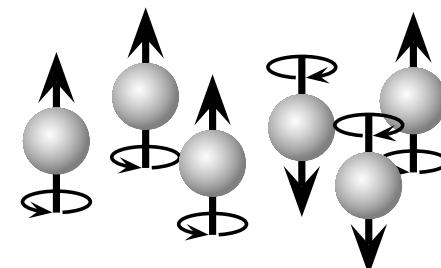
- In classical mechanics particle simply spins around its center of mass
- In quantum mechanics **spin is a truly intrinsic property of particle** (like mass and charge)
- Spin can have only two orientations in space: “up” and “down”
- Polarization (P) is a fraction of particles contributing to non-zero total spin



$$P = 100\%$$



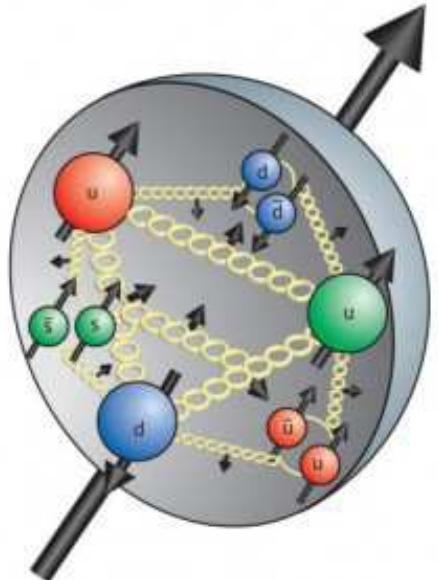
$$P = 0\%$$



$$P = 33\%$$

What Do We Study with Polarized Protons at RHIC?^{4 of 15}

- Proton is a composite particle made of **quarks and gluons**
 - At low interaction energies proton is a point-like particle
 - At high RHIC energies we see the internal structure of the protons
- Total proton spin is the sum of the spins and orbital angular momenta of the constituent **quarks and gluons**

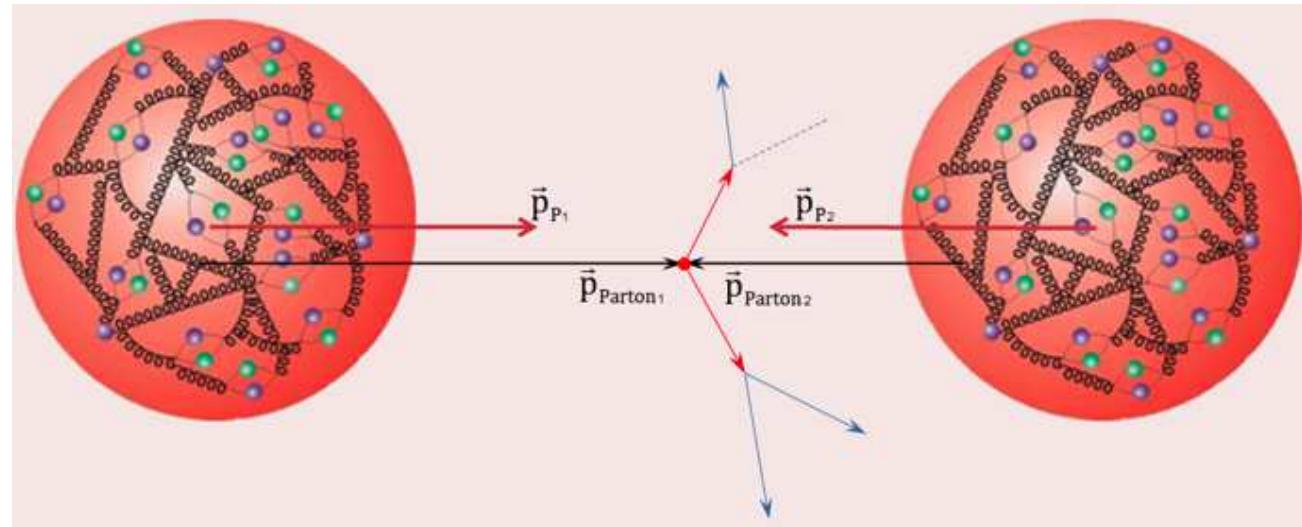


$$S_p = \frac{1}{2} = \underbrace{\langle S_q \rangle}_{\text{proton spin}} + \underbrace{\langle S_g \rangle}_{\text{gluon spin}} + \underbrace{\langle L_{q,g} \rangle}_{\text{orbital momentum ?}}$$

$\sim 30\%$ $\sim 13\%$

Extracting Knowledge from Asymmetry Measurement^{5 of 15}

- Due to spin the product of proton collisions can have spacial asymmetry w.r.t. the spin direction



- The knowledge about the internal proton structure is extracted from the measured asymmetry:

$$A = \frac{1}{P} \times \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

single spin asymmetry

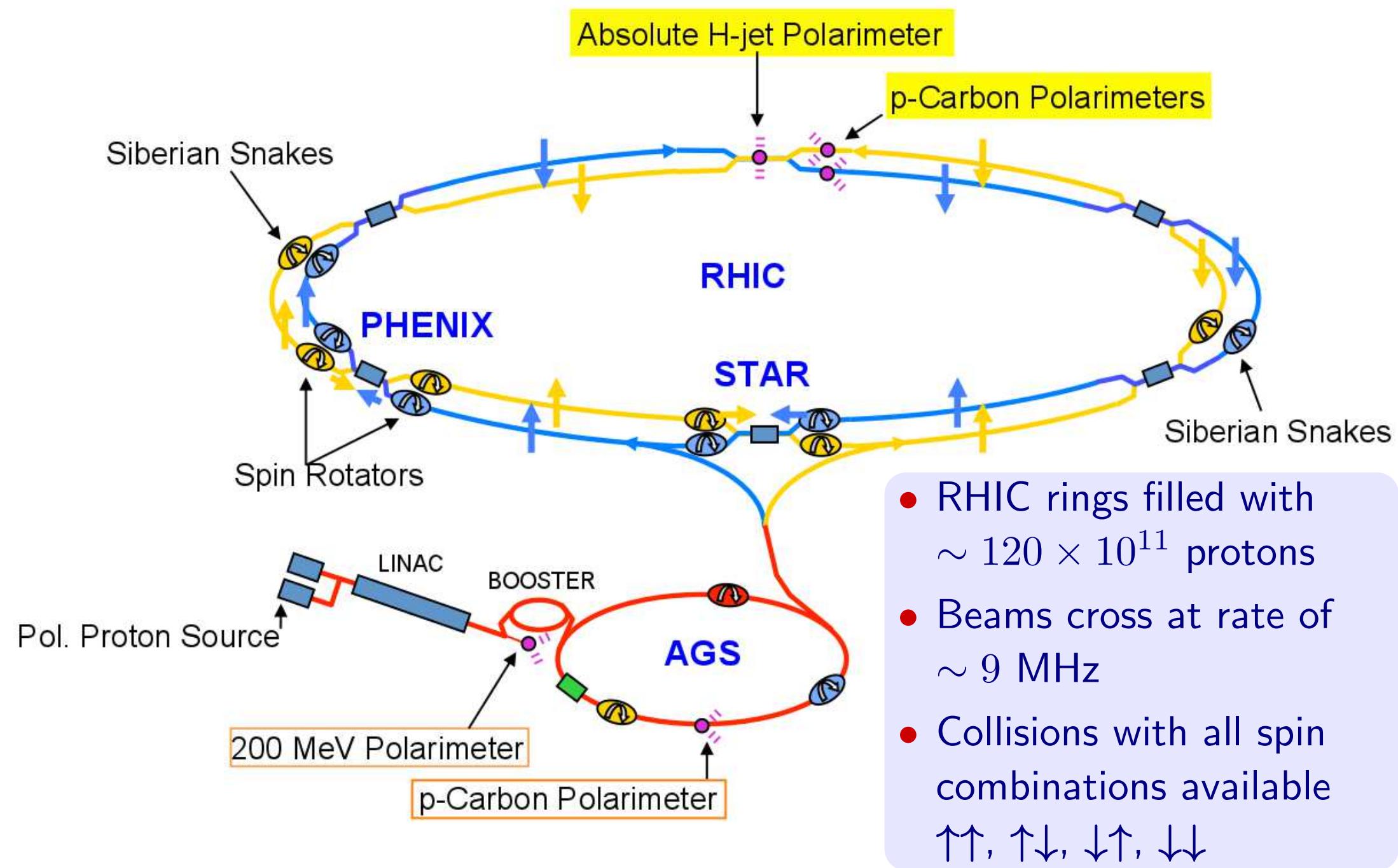
$$\mathbb{A} = \frac{1}{P^2} \times \frac{N^{\uparrow\uparrow} - N^{\uparrow\downarrow}}{N^{\uparrow\uparrow} + N^{\uparrow\downarrow}}$$

double spin asymmetry

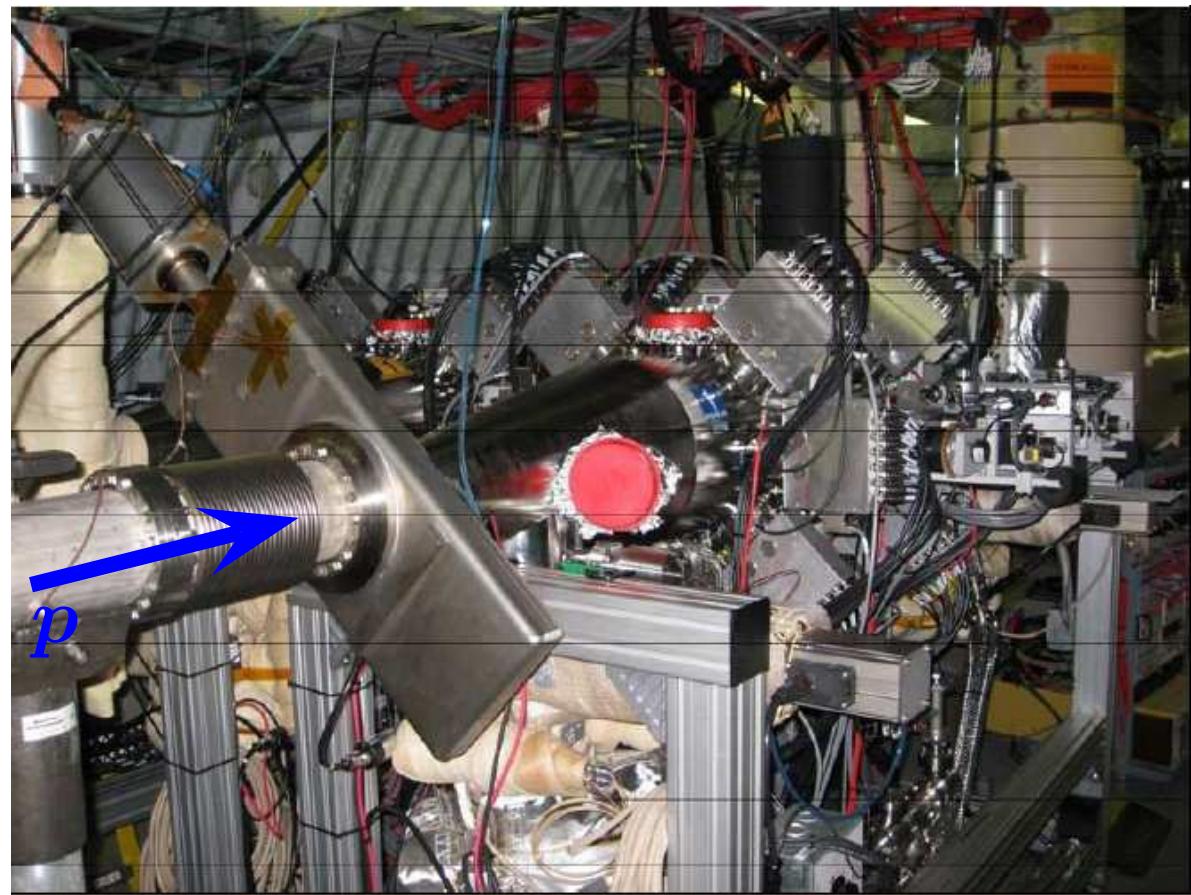
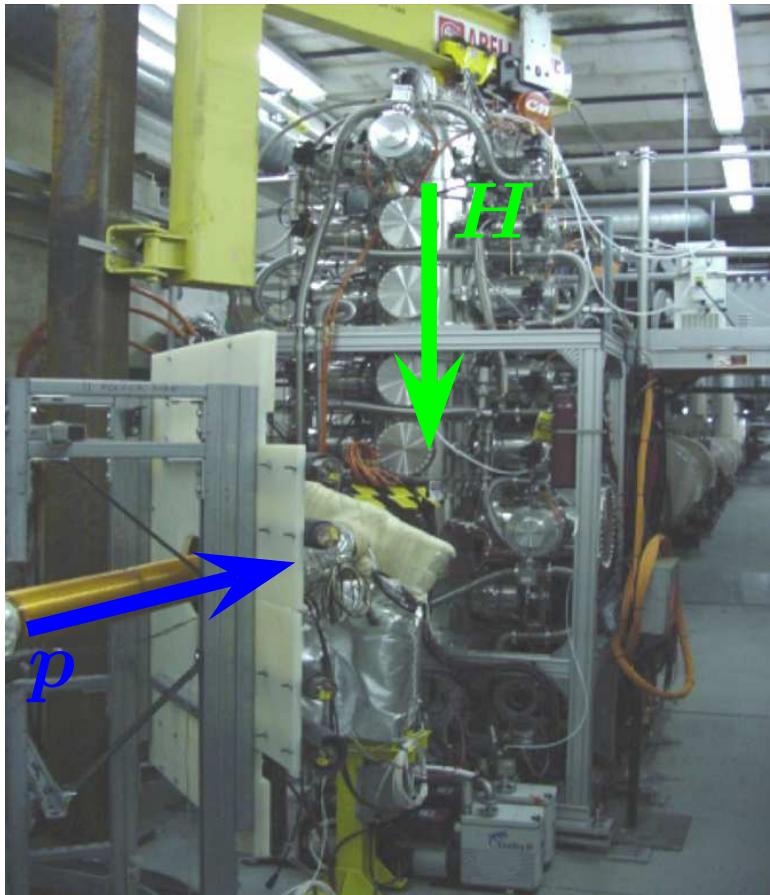
- We must know the spin direction of colliding protons (only at RHIC!)
- **Precise knowledge of polarization $P \pm \Delta P$ is essential for all spin analyses at RHIC**

Accelerator Complex and Polarimeters

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RHIC Polarimeters



- **Hydrogen Jet Polarimeter**

- Continuous operation throughout the fill ($\sim 8 - 10$ hours)
- Provides **average** polarization over the fill
- Lower statistical power

- **p-Carbon Polarimeters
(two in each ring)**

- About four 3-minute measurements per fill
- Polarization decay in fill
- Beam polarization profiles
- Higher statistical power

Principles of RHIC Polarimetry

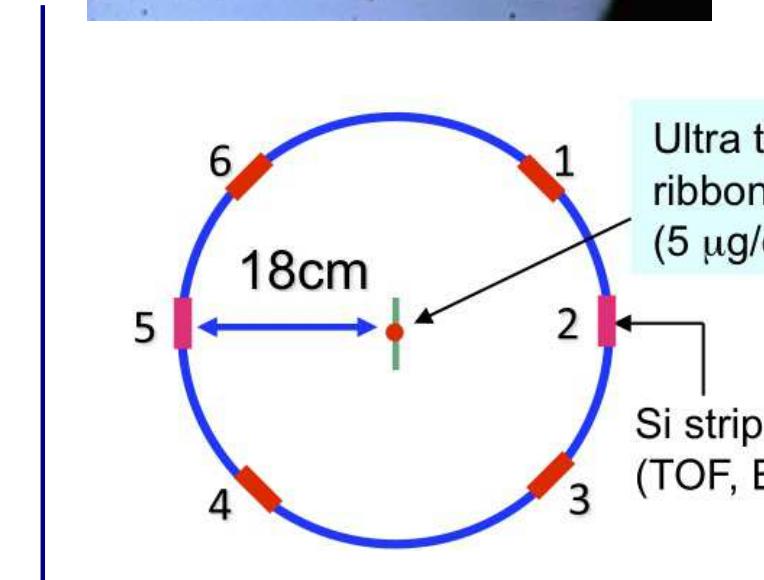
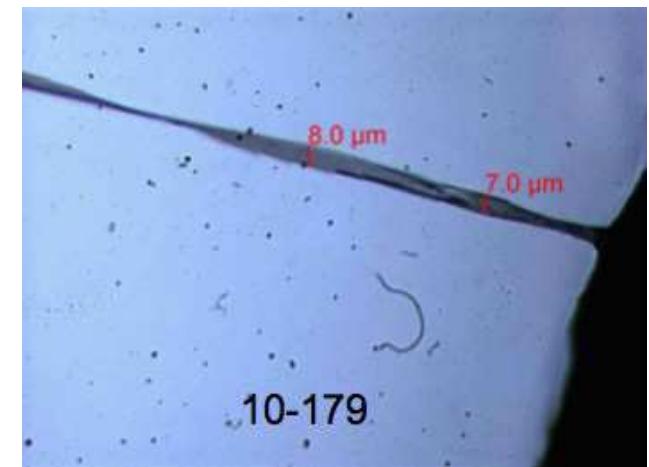
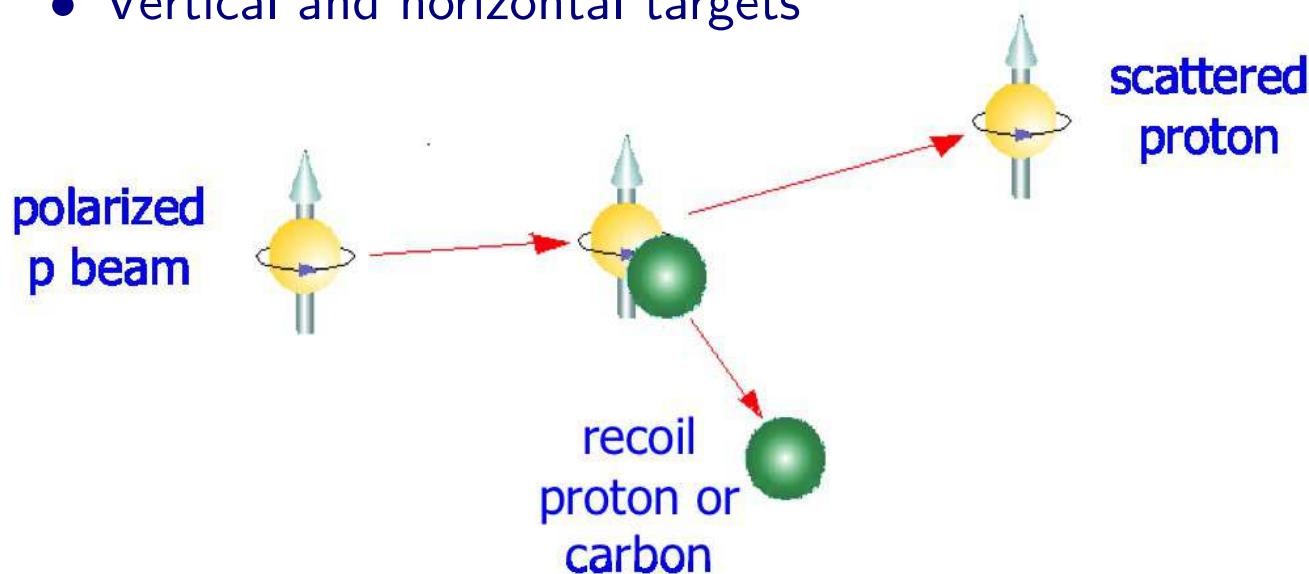
- Fixed targets are used to measure proton beam polarization

- H-jet polarimeter**

- Vertical hydrogen jet target $\sim 6 - 7$ mm in diameter

- p-Carbon polarimeters**

- Ultra thin carbon ribbon $2.5\text{ cm} \times 10\text{ }\mu\text{m} \times 25\text{ nm}$
 - Vertical and horizontal targets



- Measured polarization is: $P = \frac{1}{A_N} \times \frac{N_L - N_R}{N_L + N_R}$
- Asymmetry A_N is small $\sim 3\%$

Measuring Beam Profile

Measuring Beam Profile

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Measuring Beam Profile

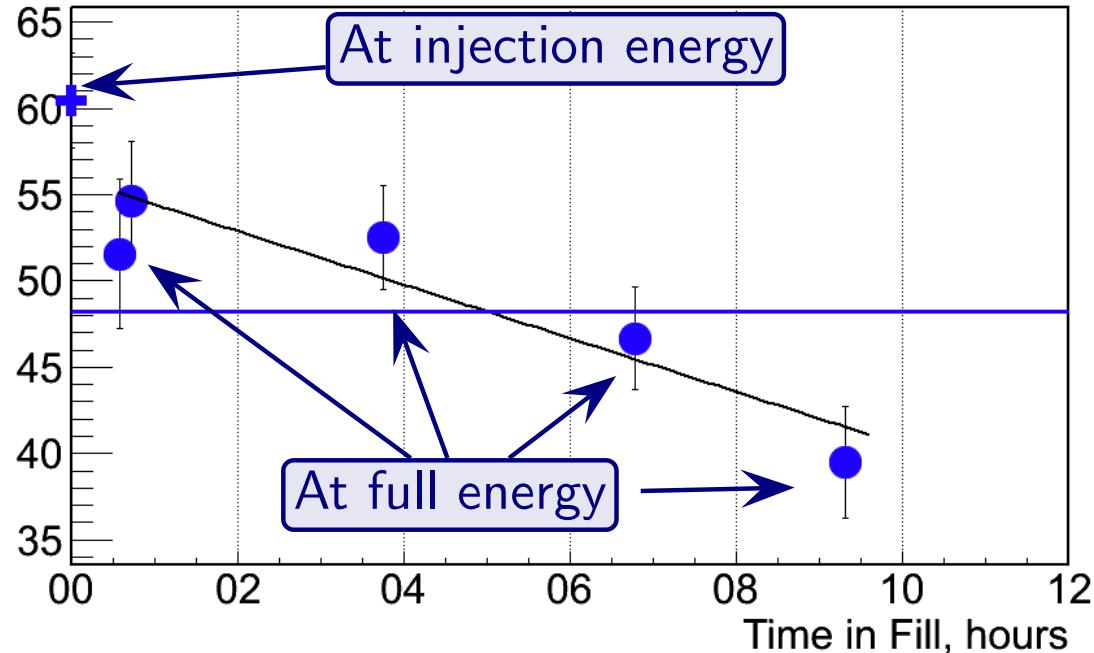
- Polarization and intensity profile can be described with gaussian distributions:

$$P = P_{\max} e^{-\frac{\vec{x}^2}{\sigma_P^2}}, \quad I = I_{\max} e^{-\frac{\vec{x}^2}{\sigma_I^2}}$$

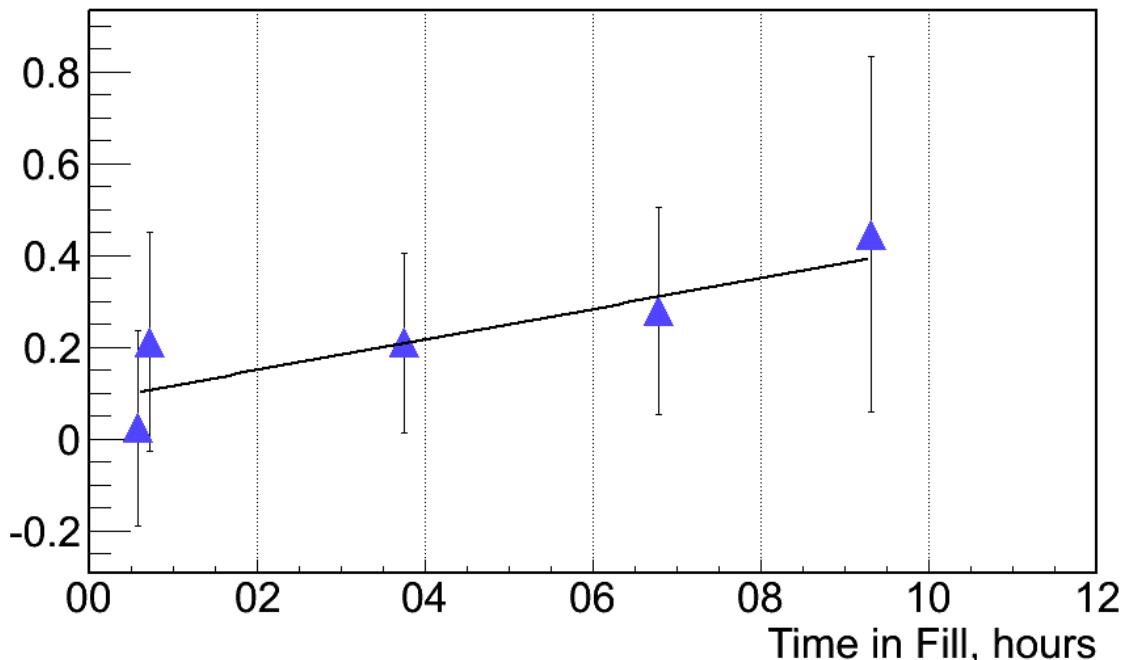
- Profile parameter
$$R = \frac{\sigma_I^2}{\sigma_P^2}$$

- Inserting something in a high energy beam is fun 😊
- Main instability in polarization measurements is believed to be due to uncertainty in target position while moving through the beam

Polarization Losses in a Fill

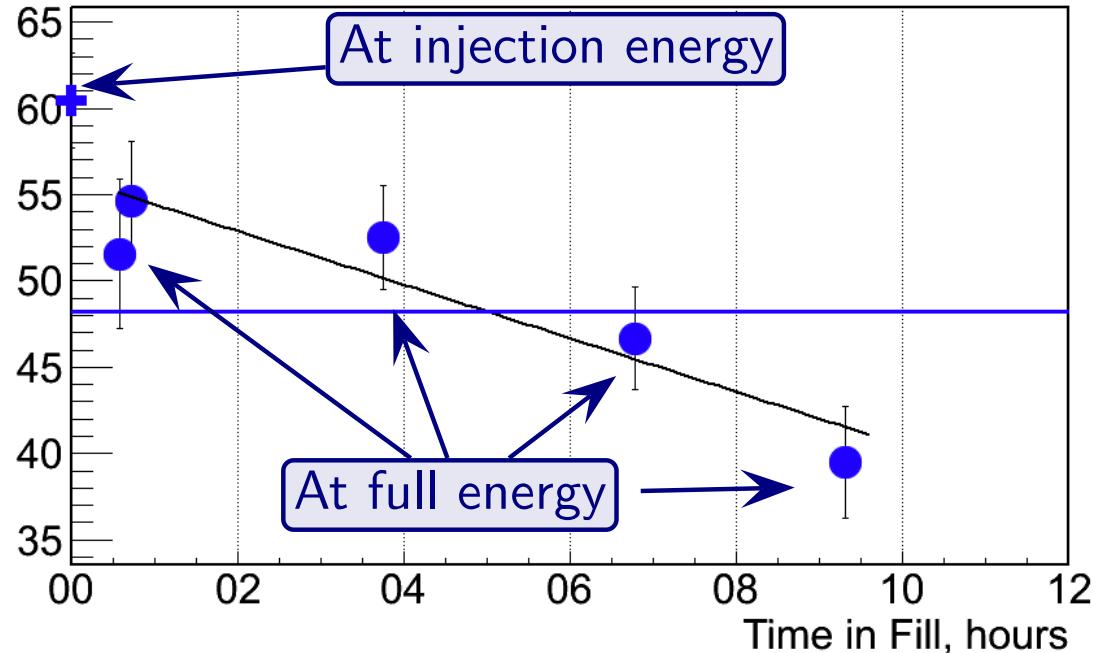


- Polarization is lost during beam acceleration
- Polarization decreases during the fill while R increases
- Our measurement confirms de-polarizing mechanism due to widening of polarization profile



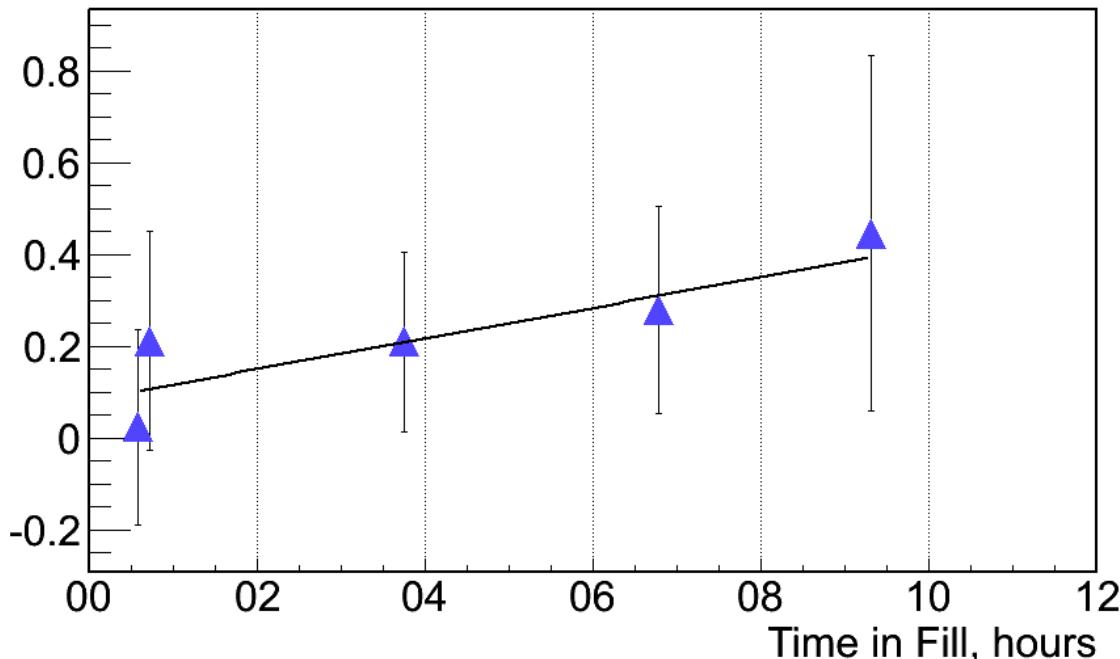
Some Numbers to Remember

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- Initial beam polarization at the source is $\sim 80\%$
- In RHIC average beam polarization was **52 %** and **58 %** for two periods in 2012

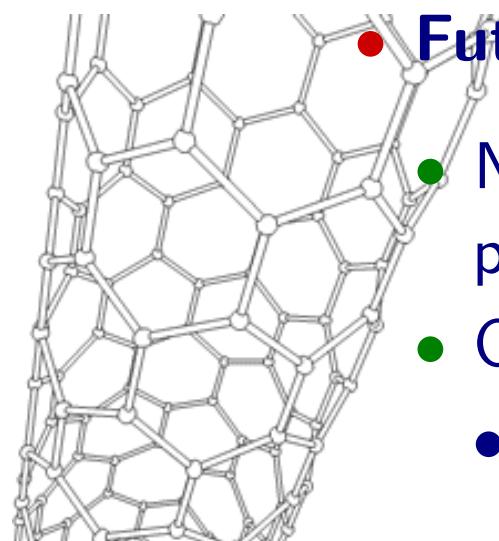
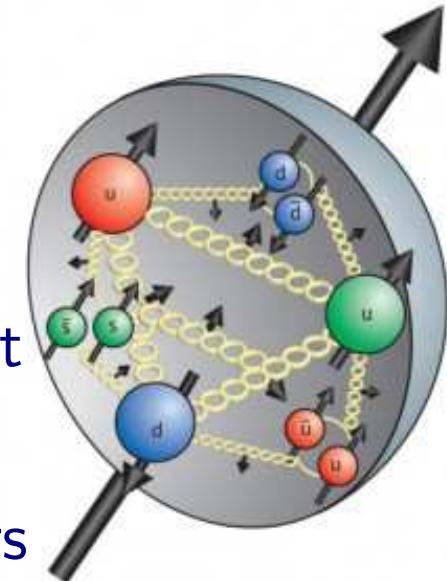
- Polarization losses are $\frac{dP}{dt} \sim -0.5\%$ per hour during a fill
- Relative measurement uncertainty per fill is $\frac{\Delta P}{P} \sim 5\%$



Summary and Outlook

- **RHIC polarimeters are unique scientific tools at BNL**

- Perform undestructive measurement of proton beam polarization
- Provide polarization measurements for all spin analyses at RHIC
- Provide valuable feedback to the RHIC machine operators



- **Future plans:**

- Next RHIC Run in 2013 we expect more data and $\sim +5\%$ in polarization
- Ongoing studies aim to improve systematic uncertainties
 - Different geometry and production techniques for carbon targets
 - Cleaner signal selection in recoil samples